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MECHANICAL CHARACTERIZATION OF DUAL PHASE AND AUSTEMPERED AISI 1040 NORMALIZED STEEL

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ABSTRCT

Mechanical properties play an important role in engineering domain. In the present investigation, mechanical properties of plain carbon steel are compared with different heat treatment processes. Tailored special-character dual phases are possible in steel compared with normalized and Austempered conditions. Ferrite-Bainite structure is one of the dual phases possible in hypo-eutectoid steels by closely regulating process variables. Tensile strength and hardness of dual phase steels are better as compared with normalized and as bought conditions. Percentage elongation of normalized and Austempered conditions are also superior. Impact energy absorption of the specimen in Austempered condition reveals improved result compared to other conditions. Volume formation of different phases has been analyzed using SEM.

KEYWORDS: Dual Phase Steel, Microstructure, Heat Treatment, AISI 1040 Steel & Ferrite-Bainite

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Original Article

INTRODUCTION

Recent year's development of materials and utilization has been increasing to meet quality challenges in many folds, especially steel, as it has the prospect to grow as a structural material, if strength and toughness factors increase with decrease in weight of the component, by increasing the volume. It is a well-known fact that the properties of metallic materials are largely affected by microstructural features, including the spatial distribution of phases, grains, inclusions and defects [1]. One of the possible paths to alter the microstructural features, intern on characteristics is heat treatment. In the present investigation, plain carbon AISI 1040 is used for the investigation of different properties of the material under different heat treatment processes, especially Ferrite-Bainite state.

Dual phase steel is a special variety of low or medium carbon steel obtained by controlled heat treatment. Generally, before the treatment, such steel consists of ferrite and cementite as equilibrium phases at the room temperature. The ferrite phase is soft and cementite is hard and is in a brittle phase. The lamellar structure of ferrite and cementite present in steel at room temperature is termed as pearlite. Ferrite phase getting separated before pearlite forms is called pro-eutectoid ferrite. Pearlite contains well-distributed ferrite and cementite as alternate

layers. The weight percentage of pearlite and pro-eutectoid ferrite in the given steel is the function of carbon content alone. In the hardening treatment, it is possible to convert pearlite phase into martensite or bainite by controlled heating and quenching cycle. In the hypo eutectoid steel, it is possible to vary the weight percentage of martensite in pro-euctectoid ferrite depending on the intercritical heating temperature and soaking time. The microstructure of such steels generally reveals islands of martensite embedded in ferritic matrix. The combined phase of pro-eutectoid ferrite and bainite is possible when steel is heated to intercritical temperature range followed by isothermal holding in the bainitic temperature range and air cooling. The improvement in the machinability and the related properties depends upon the temperature of heating in the intercritical temperature range, soaking time and rate of quenching. The typical microstructure of dual phase steel is displayed in figure 3.

While hypo-eutectoid steel is heated between critical temperatures, undergoes partial transformation to austenite, some amount of ferrite remains untransformed with change in transformation phenomena and volume fraction of dual phase changes. Even though the process is similar to Austempering treatment, there is change in the percentage of amount of austenite forming on heating to the intercritical temperature ranges. Depending on the quenching media and heat treatment temperature, type and amount of phase forming will change [2]. Formation of Ferrite – Bainite structure under intercritical temperatures 750 to 790°C is selected. Generally, as the intercritical temperature increases, the amount of Austenite formation increases and depending upon the subcritical temperature type and method of quenching, quantity of Bainite in two-phase structure increases. In the present investigation, 350°C temperature and $NaNo_2$ and $NaNo_3$ salt bath is used for Ferrite-Bainite dual phase structure. The relative weight fractions of Ferrite and other harder phase (obtained from Austenite) at a particular intercritical temperature can be obtained by lever rule [3].

AISI 1040 is also known as 080M40. It is an unalloyed medium carbon, medium strength steel and is a famous grade of thorough hardening steel, and is available in rolled or normalized conditions. It is generally made available in untreated conditions in shapes like round hot rolled, round drawn or turned, square and hexagonal flats and plate. It can be easily machined under annealed condition. Axles, gears, bolts, shafts and studs are manufactured from this grade of steel. Surface-hardened components with improved wear resistance and hardness (Rc 50–55) can be manufactured by induction of hardening treatment. EN8 is also obtained in free machining version and after heat treatment, it gives homogenous metallurgical structure and provides constant machining properties. Therefore, it is advisable to have substantial sizes of EN8 getting supplied in untreated conditions such that after initial stock removal any desired form of heat treatment can be done to it such that good mechanical properties can be obtained according to the application. Table 1 displays the typical chemical composition of AISI 1040 steels.

MATERIAL AND METHODOLOGY

The elemental components of AISI 1040 steel used in the present work is displayed in table 1.

Table 1: Elemental Breakup of AISI 1040 Steel

Element	Wt.%
C	0.43
Si	0.19
Mn	0.761
Mo	0.0012
Ti	0.006
V	0.004
W	0.045

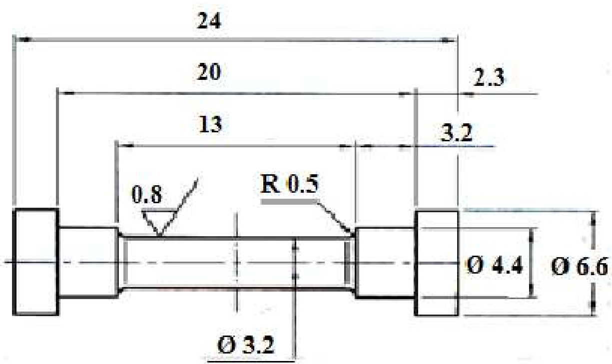
P	0.023
S	0.024
Cu	0.056
Al	0.045
Fe	98.38

Specimen Preparation

The raw steel materials purchased are bar stocks of diameter 16 mm. Specimens are prepared for tensile, impact and hardness tests. The hardness test specimens are also used for microstructure analysis.

Tensile Test

Tensile specimens (figure 1) are prepared as per ASTM E8M standard. Turning operation is carried out on CNC turning center. The tensile test is carried out on computerized tensometer (Kudale instruments Model-PC 2000).

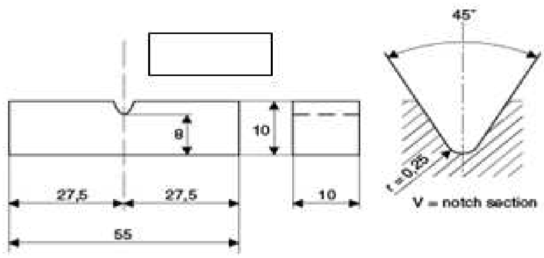


All dimensions are in mm

Figure 1: Tensile Test Specimen (ASTM E8M).

Impact (Charpy) Test

Specimens are prepared as per ASTM E23-020 standard-Type A (figure 2).



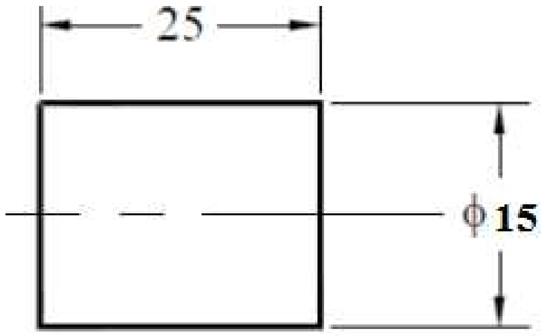
All dimensions are in mm

Figure 2: Charpy Test Specimens with its Dimensional Tolerances (ASTM E23-020).

The bar stocks are first cut in to 112 mm lengths using power blade hacksaw. Facing and plain turning operations are carried out on centre lathe. The periphery of each job is divided into four equal parts in order to identify the portions to be machined by the subsequent shaping operation. Each job is cut in to two halves, again by power hacksaw. By carrying out the shaping operation, the four sides are machined to 10 mm x 10 mm dimensions. The impact testing machine used for the study (IT-30, Fuel Instruments and Engineers Pvt. Ltd.)

Hardness (Rockwell Hardness) Test

Specimens are prepared as displayed in figure 3. The bar stocks are cut in to 25 mm length on power blade hacksaw. The facing operation is carried out on CNC turning centre.



All dimensions are in mm

Figure 3: Hardness Test Specimen

Hardness test is carried out using Rockwell hardness testing machine (Akash Industries model, A1-Twin). The bar stock is cut in to 25 mm length on power blade hacksaw. The ASTM E18-02 procedure is followed for the hardness test.

Heat Treatment Procedure

ASTM standard specimens are prepared for the heat treatment process and characterization study. Initially, normalizing treatment has been carried out. The set of specimens are heated to above the upper critical temperature i.e., 900°C and holding it for two hours isothermally in a furnace after cooling in air to get the homogenous structure.

Dual-Phase Treatment

The normalized specimens are further heated to intercritical temperature (790^{o}C), isothermally holding for two hours and shifting the specimen to anther furnace having salt bath in subcritical temperature, i.e., 350°C for 30 minutes after that cooling in room temperature. This treatment develops microstructure with different wt.% of Bainite embedded in fine Ferrite matrix [4]. This heat treatment process is displayed in figure 4.

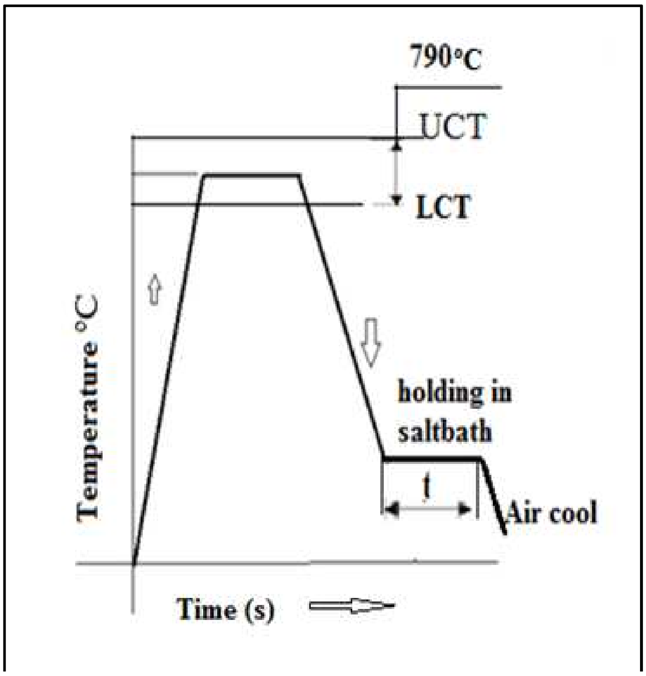


Figure 4: Dual-Phase Heat Treatment Cycle to Obtain Ferrite-Bainite Structure.

Set of specimens are heated to above the upper critical temperatures, i.e., 900°C for two hours followed by quenching in salt bath comprising of sodium nitrate and nitrite (equal proportions by weight) isothermally at 350°C for 30 minutes and cooling in air to room temperature. This treatment refines the pearlite colony with finer randomly placed well-dispersed ferrite and cementite phases [5]. Austempering process is as displayed in figure 5.

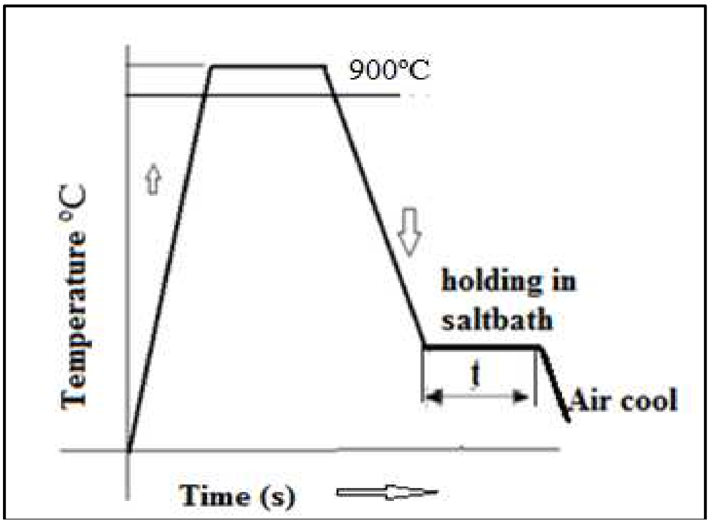


Figure 5: Austempering Treatment Cycle.

RESULTS AND DISCUSSIONS

Hardness

Figure 6 displays the result of bulk hardness verses heat treatment type for different specimens of AISI 1040 steel. As bought displays lower hardness values as compared to normalized. Austempered displays excellent hardness compared to dual phase conditions. The % increases in hardness in Austempered dual phase and normalizes at 1,15,100 and 25, respectively over as-bought condition. There is an excellent hardness in Austempered condition due to the fineness and

morphology of ingredient phase in Bainite structure [6]. The comparable in mean (100%) in hardness in dual phase is due to the formation of larger amount of Bainite with independent ferrite phase. The partial Austenization temperature (790°C) for dual phase is very much due to upper critical temperature (830°C) of the steel used here. Since 790°C is near to 830°C, large amount of austenite forms on heating to 790°C, on quenching isothermal holding at 350°C, the austenite converts into lower Bainite. The better hardness of this combined phase is due to the synergetic nature of Bainite and independent Ferrite.

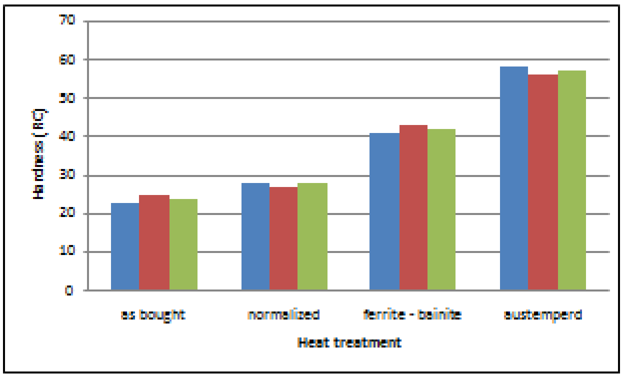


Figure 6: Variation of Hardness Under Different Heat Treatment Processes.

Tensile Strength

Figure 7 displays UTS comparison of different heat-treated specimens under study. The normalized condition displays 25% increase in UTS and Ferrite-Bainite (dual phase) and Austenized condition displays on par good UTS values (approx. 100–150%) over as-bought condition. The excellent UTS in Austempered and dual phase conditions are due to the fineness, morphology and sequence of phase formation in the transformation temperature range. The small UTS reduction (5%) in dual phase over Austempered is due to the amount of Ferrite present (approx. 25% by lever rule) in the Bainite phase. Even though as bought and normalized phase morphology is same, considerable difference exists in the design fineness of phase, where normalized is finer than as bought [7]

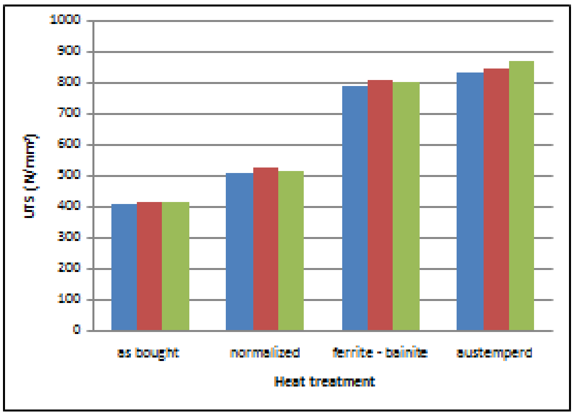


Figure 7: Variation of Tensile Strength under Different Heat Treatment Process.

3.3. Elongation

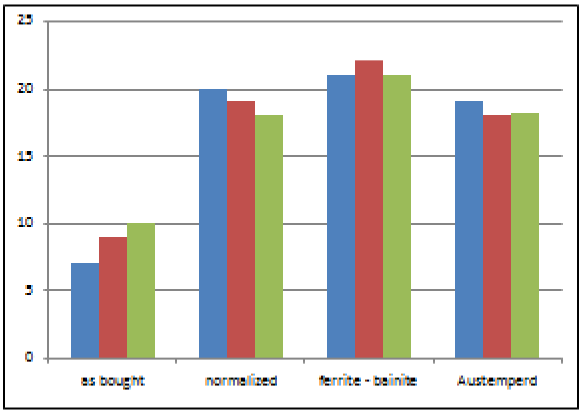


Figure 8: Variation of Elongation (%) under Different Heat Treatment Process.

Figure 8 displays the ductility (% elongation) of different heat-treated specimens. Ferrite-Bainite phase specimen displays excellent ductility compared to Austempered and Normalized. Marginal lower ductility is observed in Austempered over Normalized even though approximately 150% in mean observed over as-bought condition ductility. The three-phase matrix like ferrite and cementite (Bainite) and independent Ferrite is as possible for excellent ductility. Ferrite present in matrix [8]. The as-bought condition reveals poor ductility due to the presence of zonal microscopic segregation in chemical composition [9].

Impact Strength

Figure 9 displays impact strength distribution of heat-treated specimen under consideration. The Excellent (60% in mean) impact resistance in dual phase, moderate (40% in mean) in Austempered followed by approximately 20% in mean normalized is observed over as bought conditions. The behavior is similar to ductility trend with small fluctuation. The trend depends upon the individual behavior of minute phase present in the phase morphology [10]. The degree of fineness, a greater number of phases and inbuilt behavior of individual phase reflects the toughness in mean of the specimen. Accordingly, dual phase condition reveals excellent result in the present work.

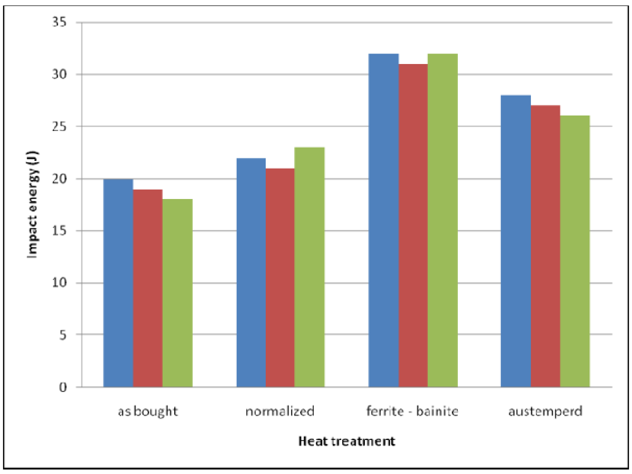


Figure 9: Variation of Impact Energy Under Different Heat Treatment Process.

Microstructure

Scanning electron microscope was used to obtain the microstructure for all the samples, which are heat treated as well as as-bought steels. Figures 10-13 displays the SEM images of steels. In most of the microstructures, the mixture of ferrite, which is needle shaped or lamellar pearlite has been observed.

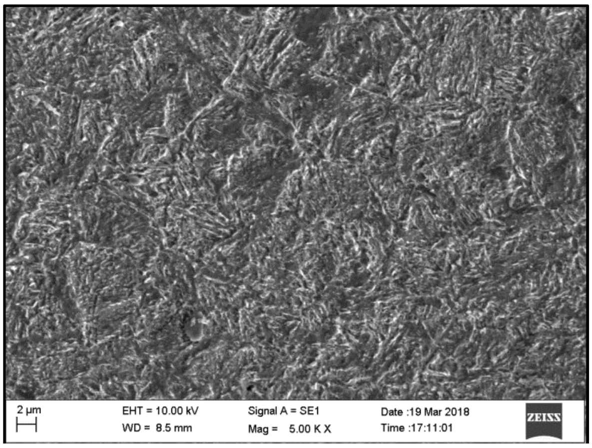


Figure 10: The Micrographs of as Bought.

The as-bought condition [figure 10] displays typical pearlite structure of plain carbon steel. It consists of larger ferrite grains with coarser lamellar pearlite colonies. Lamellar pearlite consists of coarser cementite as bought bonds in ferrite lamellar matrix. Due to the coarseness of individual phases, the strength, hardness and toughness is poor [11]

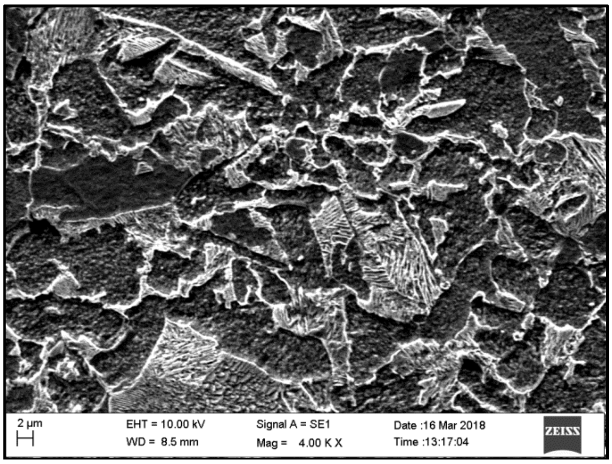


Figure 11: The Micrographs of Normalized.

Displays finer pearlite colony in ferrite matrix. The pearlite colony is not only finesse, the lamellar phases are also finer as compared to figure 11. The phase morphology supports positively for the improvement of properties.

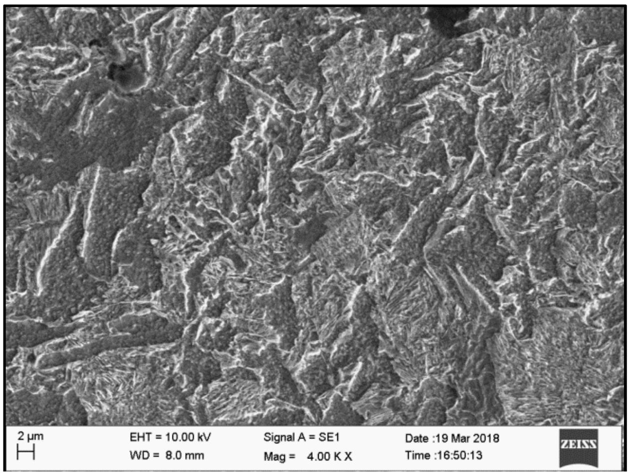


Figure 12: The Micrographs of Ferrite-Bainite.

Figure 12 displays finer ferrite phase in the network of Bainite. The degree of finesse and spreadability of ferrite in dual phase is good in that the properties are well balanced.

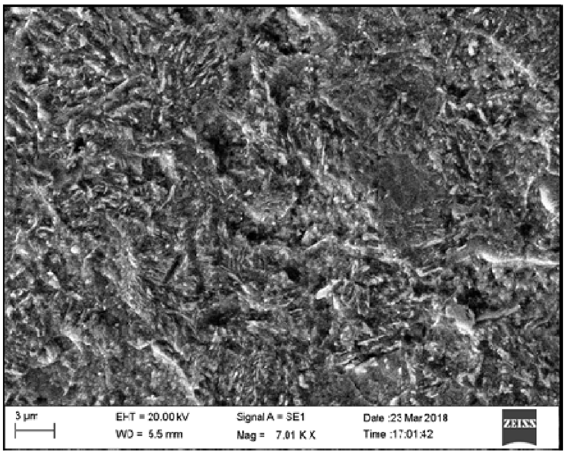


Figure 13: The Micrographs of Austempered Steel.

Figure 13 displays a typical Austempered (f - b) structure. The minute ferrite and cementite (within colonies) phases are well balanced in such a way that typical orientation (lamellar/feathery) of the two phases is not seen. Two phases are randomly mixed in the network. This is the lower Bainitic phase morphology, generally observed in the plain carbon steel [12]. Overall, phase morphology observed in SEM truly supports the property distribution trends in different heat treatment condition of AISI 1040 steel.

CONCLUSIONS

The AISI 1040 steel is successfully heat treated and the expected results are obtained in line with the set theories. The overall conclusions are highlighted below:

- Hardness of the Austempered steel is better as compared to other heat treatment conditions. As-bought steel exhibited lowest hardness.
- Tensile strength of Ferrite-Bainite dual phase steel is maximum compared to Normalized and in as received condition.

- A marginal difference in UTS is noted between dual phase steel and Austempered steel.
- Ferrite-Bainite dual phase displays excellent ductility as compared to Austempered and in Normalized condition.
- Marginal lower ductility is observed in Austempered and in Normalized structures.
- Ferrite-Bainite is found to be having better impact strength in comparison to steel under other heat treatment conditions.
- Moderate impact strength of steel is observed in Austempered condition as compared to normalized and in as-bought condition.
- Microstructure of as-bought steel has larger Ferrite grains with lamellar Pearlite structure and Normalized steel has a finer Pearlite.
- Microstructure of dual phase steel reveals the softer Ferrite and harder Bainite structure and Austempered steel displayed a randomly oriented mixed phase.

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